## 4.3 Estimating growth curves

**Derivation of growth curves at subject sites:**

| Site code | Method (SS, P, ESS, H.) | If P or ESS, name of pooling group | Distribution used and reason for choice | Any urban or non-flood years adjustments | Parameters of distribution (location, scale and shape after adjustments) | Growth factor for 100-year return period |
|---|---|---|---|---|---|---|
| KB01 | P | KB01 | GL, best fit | Urban | 1<br>0.291<br>-0.218 | 3.298 |

Methods: SS - Single Site; P - Pooled; ESS - Enhanced Single Site; H - Historical. Pooled and ESS growth curves were derived using the procedures from Science Report SC050050 (2008). Urban adjustments are carried out using the method of Kjeldsen (2010).

**Flood frequency curve plots:**

**Derivation of pooling groups:**

| Name of group | Site code from whose descriptors group was derived | Subject site treated as gauged? (ESS) | URBEXT2000 threshold applied to pooling group selection? | L-moments deurbanised (including subject site for ESS)? | Small catchment pooling procedure applied? |
|---|---|---|---|---|---|
| KB01 | KB01 | No | 0.03 | Yes | Yes |

Methods: Unless otherwise stated, pooling groups were derived using the procedures from Science Report SC050050 (2008). The small catchment pooling procedure is given in the report on Phase 2 of project SC090031 (2021) and implemented in WINFAP v5.

**Pooling group composition:**

| Name of group | Changes made to default pooling group, with reasons | Weighted average L-moments |
|---|---|---|
| PG01 | According to EA recommendation[3], gauge 26017 Ings Beck@South Newbald was removed from the default pooling group. This was found to be heterogeneous. A review of the pooling group was undertaken based on the distribution of L-moments. Therefore, the NRFA gauges 27073, 25019, 27051, 39033, 33054, 7011 were all further investigated. The review of information available on the NRFA did not provide justification for the removal of theses gauges from the default pooling group. No other gauge has been | 0.305<br>0.197 |

| Name of group | Changes made to default pooling group, with reasons | Weighted average L-moments |
|---|---|---|
| | added to the pooling group. | |

## 4.4 Final choice of QMED and growth curves

**Method choice and reasons:**

| Site code | Final choice of QMED and reasons | Final choice of flood growth curve method and reasons |
|---|---|---|
| RB01 | Urban/donor adjusted QMED; best estimate based on available data | |
| TD01 | Urban/donor adjusted QMED; best estimate based on available data | |
| SD01 | Urban/donor adjusted QMED; best estimate based on available data | |
| KB01 | Urban/donor adjusted QMED; best estimate based on available data | Pooled growth curve based on GL distribution, small catchments pooling method. Best fit. |

**Final flood estimates from stationary statistical methods:**

| Site code | 2 50% | 5 20% | 10 10% | 30 3.3% | 50 2% | 100 1% | 200 0.5% | 500 0.2% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | 0.164 | 0.241 | 0.298 | 0.401 | 0.456 | 0.541 | 0.639 | 0.792 | 0.931 |
| TD01 | 0.164 | 0.241 | 0.298 | 0.401 | 0.456 | 0.541 | 0.639 | 0.792 | 0.931 |
| SD01 | 0.075 | 0.110 | 0.137 | 0.183 | 0.209 | 0.247 | 0.292 | 0.362 | 0.426 |
| KB01 | 0.814 | 1.197 | 1.481 | 1.99 | 2.263 | 2.683 | 3.169 | 3.932 | 4.618 |

Flood peak in $m^3/s$ for the return periods in years or AEP (%) events.

# 5. Non-stationary statistical methods

## 5.1 Method Overview

**What is the purpose of applying these methods?**

**What methods will be used?**

| Site code | If ungauged, which gauging station is being used? | Methods used to test for trends and change points | Methods used for non-stationary frequency analysis |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

## 5.2 Testing for trends and change points

**Non-parametric trend tests:**

**Step change tests:**

**Split sample tests:**

**Interpretation and conclusions:**

## 5.3 Non-stationary frequency analysis

**Selection of covariates:**

**Fitting non-stationary models:**

**Interpretation and conclusions:**

**Final flood estimates from non-stationary statistical methods:**

| Site code | 2 50% | 5 20% | 10 10% | 20 5% | 30 3.3% | 50 2% | 75 1.3% | 100 1% | 200 0.5% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

Flood peak in $m^3/s$ for the return periods in years or AEP (%) events.

# 6. Revitalised flood hydrograph (ReFH1) method

## 6.1 Method Overview

**What is the purpose of applying this method?**

**Rural and urban catchment sub-divisions:**

## 6.2 Model Parameters

**Summary of model parameters:**

| Site code | Method | Tp (hours) rural | Tp (hours) urban | Cmax (mm) | BL (hours) | BR | $PR_{imp}$ % |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Methods: OPT: Optimisation from event analysis, BR: Baseflow recession fitting, LAG: TP from lag analysis, CD: Catchment descriptors, DT: Data transfer, CAL: model calibration.

**Analysis undertaken to derive model parameters:**

## 6.3 Model inputs for design events

**Design events for lumped catchments:**

| Site code | Rainfall DDF model | Urban or rural | Season of design event | Storm duration (hrs) | Initial soil moisture Cini | Initial baseflow BFO |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**Design events for subcatchments and intervening areas:**

| Site code(s) | Rainfall DDF model | Season of design event | Storm duration (hrs) | Storm area for ARF | Areal reduction factor (ARF) | Reason for selecting storm |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**Storm duration testing:**

---

## 6.4 Final choice of ReFH1 flow estimates

**Method choice and reasons:**

| Site code | Final choice of design inputs and model parameters |
|---|---|
| | |
| | |
| | |
| | |

**Final flood estimates from ReFH1 method:**

| Site code | 2 50% | 5 20% | 10 10% | 20 5% | 30 3.3% | 50 2% | 75 1.3% | 100 1% | 200 0.5% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

Flood peak in $m^3/s$ for the return periods in years or AEP (%) events.

---

# 7. Revitalised flood hydrograph 2 (ReFH2) method

## 7.1 Method Overview

**What is the purpose of applying this method?**

**Rural and urban catchment sub-divisions:**

**Version of ReFH2 applied:**

## 7.2 Model Parameters

**Summary of model parameters:**

| Site code | Method | Tp (hours) rural | Cmax (mm) | BL (hours) | Area modelled as urban (km2) | TP urban scaling factor | IF | IRF | DS |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | CD | 4.123 | 918.421 | 52.417 | 0.0848 | 0.75 | 0.4 | 0.7 | 0.5 |
| TD01 | CD | 3.798 | 1081.717 | 52.635 | 0.8428 | 1 | 0.4 | 0.7 | 0.5 |
| SD01 | CD | 2.575 | 590.556 | 39.883 | 0.0696 | 0.75 | 0.4 | 0.7 | 0.5 |
| KB01 | CD | 6.624 | 810.759 | 60.14 | 2.533 | 0.75 | 0.4 | 0.7 | 0.5 |

Methods: OPT: Optimisation from event analysis, BR: Baseflow recession fitting, LAG: TP from lag analysis, CD: Catchment descriptors, DT: Data transfer, CAL: model calibration.

**Analysis undertaken to derive model parameters:**

## 7.3 Model inputs for design events

**Design events for lumped catchments:**

| Site code | Rainfall DDF model | Urban or rural | Highly permeable? | Season of design event | Storm duration (hrs) | Initial soil moisture Cini | Initial baseflow BFO |
|---|---|---|---|---|---|---|---|
| RB01 | DDF13 | Rural | Yes | Winter | 6.5 | 60.746 | 0 |
| TD01 | DDF13 | Rural | Yes | Summer | 6.5 | 27.742 | 0 |
| SD01 | DDF13 | Rural | No | Winter | 4.5 | 79.134 | 0.004 |
| KB01 | DDF13 | Rural | Yes | Winter | 11 | 65.455 | 0 |

**Design events for subcatchments and intervening areas:**

| Site code(s) | Rainfall DDF model | Season of design event | Storm duration (hrs) | Storm area for ARF | Areal reduction factor ARF | Reason for selecting storm |
|---|---|---|---|---|---|---|
| | | | | | | |
| To be finalised in the next stage of analysis | | | | | | |

**Storm duration testing:**

To be carried out in the next stage of analysis and is going to be based on a selection of design storms to be applied to all lumped inflows and subcatchments in order to represent to occurrence of conditions maximizing flood risk to the site.

---

## 7.4 Final choice of ReFH2 flow estimates

**Method choice and reasons:**

| Site code | Final choice of design inputs and model parameters |
|---|---|
| | |
| To be finalised in the next stage of analysis | |

**Final flood estimates from ReFH2 method:**

| Site code | 2 50% | 5 20% | 10 10% | 30 3.3% | 50 2% | 100 1% | 200 0.5% | 500 0.2% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | 0.17 | 0.25 | 0.31 | 0.41 | 0.47 | 0.56 | 0.67 | 0.85 | 1 |

| Site code | 2 50% | 5 20% | 10 10% | 30 3.3% | 50 2% | 100 1% | 200 0.5% | 500 0.2% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|
| TD01 | 0.31 | 0.45 | 0.55 | 0.73 | 0.83 | 0.98 | 1.16 | 1.45 | 1.7 |
| SD01 | 0.07 | 0.1 | 0.12 | 0.16 | 0.18 | 0.22 | 0.26 | 0.32 | 0.38 |
| KB01 | 0.62 | 0.89 | 1.09 | 1.45 | 1.66 | 1.99 | 2.38 | 3 | 3.53 |

Flood peak in $m^3/s$ for the return periods in years or AEP (%) events.

# 8. Other Rainfall-Runoff or Hydrograph Methods

## 8.1 Averaged Hydrograph Shapes

## 8.2 FSR-FEH Rainfall-Runoff Method

## 8.3 Direct Rainfall Modelling

# 9. Discussion and summary of results

## 9.1 Comparison of results from different methods

| Site code | *Ratio of ReFH2 to stationary statistical peak, 50% AEP* | *Ratio of ReFH2 to stationary statistical peak, 1% AEP* |
|---|---|---|
| RB01 | 1.037 | 1.035 |
| TD01 | 1.89 | 1.812 |
| SD01 | 0.933 | 0.889 |
| KB01 | 0.762 | 0.742 |

## 9.2 Final choice of method

**Choice of method and reasons:**

The statistical estimates (with QMED from catchment descriptors and adjusted by donor transfer and for urbanisation) have been selected as final. A comparison between statistical and ReFH2 estimates has highlighted that there is a discrepancy between the two methods, with over or under estimation from either of them which is not consistent across all subject catchments. However, for all sites but SD01 current FEH guidelines would recommend the statistical method in preference to ReFH2, given the characteristics of the subject sites. Therefore, the statistical method has been selected to derive the final peak estimates at all sites. Hydrograph shapes are from ReFH2 and design hydrographs are derived from ReFH2 hydrographs scaled to match the statistical peaks. Design flows for the intervening area IC01 have been obtained from design flows estimated at KB01 scaled down by the ratio of catchment areas.

**How will the 0.1% AEP flows be estimated?**

Peak flows from Statistical method

**How will the flows be applied to a hydraulic model?**

Lumped inflows at RB01, TD01, and SD01. Design flows for the intervening area IC01 (see 9.3) are going to be applied as lumped or distributed inflows across all subcatchments defined on the basis of the results of the direct rainfall modelling.

## 9.3 Final results

| Site code | 2 50% | 5 20% | 10 10% | 30 3.3% | 50 2% | 100 1% | 200 0.5% | 500 0.2% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | 0.164 | 0.241 | 0.298 | 0.401 | 0.456 | 0.541 | 0.639 | 0.792 | 0.931 |
| TD01 | 0.164 | 0.241 | 0.298 | 0.401 | 0.456 | 0.541 | 0.639 | 0.792 | 0.931 |
| SD01 | 0.075 | 0.110 | 0.137 | 0.183 | 0.209 | 0.247 | 0.292 | 0.362 | 0.426 |
| KB01 | 0.814 | 1.197 | 1.481 | 1.99 | 2.263 | 2.683 | 3.169 | 3.932 | 4.618 |
| IC01 | 0.431 | 0.634 | 0.784 | 1.054 | 120% | 1.420 | 1.678 | 2.082 | 2.445 |

Flood peak in $m^3/s$ for the return periods in years or AEP (%) events.

**Design storms applied in the hydraulic model:**

| Site code(s) | Season of design event | Storm duration (hrs) | Storm area for ARF (km2) | Return period(s) | Reason for selecting storm |
|---|---|---|---|---|---|
| | | | | | |
| To be selected in the next stage of analysis | | | | | |

**Climate change allowances:**

---

## 9.4 Checks

**Growth factor checks:**

| Site code | 1% AEP growth factor | 0.1% AEP / 1% AEP ratio |
|---|---|---|
| KB01 | 3.296 | 1.721 |

**Specific discharge:**

| Site code | 2 50% | 5 20% | 10 10% | 20 5% | 30 3.3% | 50 2% | 75 1.3% | 100 1% | 200 0.5% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

Flood peak in l/s/ha for the return periods in years or AEP (%) events.

**Spatial consistency of results:**

To be assessed when hydrological assessment is finalised

**Return periods for notable historic floods:**

NA

**Compatibility with longer-term flood history:**

NA

**Comparisons with previous studies:**

NA

**Checks on hydraulic model results:**

Not carried out at this stage of analysis

---

## 9.5 Assumptions, limitations, and uncertainty

**Assumptions (specific to this study):**

- QMED and pooling suitability assessed on the basis of information available on the NRFA; no local gauge available
- Adjustment to catchment boundaries and distribution of contributing runoff to local watercourses is made in accordance to the topography of the area and the results of a direct rainfall model. Thus, it is assumed that surface runoff processes are most likely to inform a correct representation of the subcatchments contributions across the study area.

**Limitations:**

- Statistical method applied outside AEPs range of applicability;
- Hydrological catchments of interest are all ungauged. Hydrological response is highly affected by local topographical features and alterations to hydrological connectivity due to artificial drainage. While a better understanding of flow paths within the area of interest has been achieved through direct rainfall modelling, the lack of local hydrometric data remains a key limitation in the results.

**Uncertainty:**

| Site code | 50% AEP Lower 95% | 50% AEP Upper 95% | 5% AEP Lower 95% | 5% AEP Upper 95% | 1% AEP Lower 95% | 1% AEP Upper 95% | 0.1% AEP Lower 95% | 0.1% AEP Upper 95% |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| To be assessed when hydrological assessment is finalised | | | | | | | | |

Upper and lower 95% confidence bounds for the flood peak in $m^3/s$ for the AEP (%) events.

**Suitability of results for future studies:**

Assessment of flood risk specific to the area of interest of current project.

**Recommendations for future work:**

To be made when hydrological assessment is finalised

# 10. Appendix

## 10.1 Digital files

### Input data:

### Project or calculation files:

### Output data:

## 10.2 Other Supporting Information

*Table 1 Pooling group at KB01*

| | Station | Distance (SDM) | Years of data | QMED AM | L-CV Observed | L-CV Deurbanised | L-SKEW Observed | L-SKEW Deurbanised | Discordancy |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 27073 (Brompton Beck @ Snainton Ings | 0.585 | 41 | 0.820 | 0.212 | **0.213** | 0.006 | **0.005** | 0.838 |
| 2 | 26016 (Gypsey Race @ Kirby Grindalythi | 0.589 | 24 | 0.103 | 0.304 | **0.304** | 0.240 | **0.240** | 0.088 |
| 3 | 36010 (Bumpstead Brook @ Broad Gree | 0.600 | 54 | 7.545 | 0.372 | **0.374** | 0.168 | **0.167** | 1.183 |
| 4 | 26014 (Water Forlornes @ Driffield) | 0.829 | 23 | 0.437 | 0.315 | **0.316** | 0.164 | **0.163** | 0.350 |
| 5 | 25019 (Leven @ Easby) | 0.842 | 43 | 5.677 | 0.334 | **0.335** | 0.373 | **0.372** | 0.747 |
| 6 | 27051 (Crimple @ Burn Bridge) | 0.997 | 49 | 4.564 | 0.217 | **0.218** | 0.143 | **0.142** | 0.785 |
| 7 | 39033 (Winterbourne Stream @ Bagnor) | 1.058 | 59 | 0.403 | 0.338 | **0.338** | 0.375 | **0.375** | 1.178 |
| 8 | 36004 (Chad Brook @ Long Melford) | 1.066 | 54 | 4.873 | 0.301 | **0.302** | 0.170 | **0.169** | 0.458 |
| 9 | 33054 (Babingley @ Castle Rising) | 1.067 | 45 | 1.136 | 0.229 | **0.229** | 0.183 | **0.182** | 1.109 |
| 10 | 7011 (Black Burn @ Pluscarden Abbey) | 1.102 | 9 | 5.205 | 0.491 | **0.491** | 0.521 | **0.521** | 2.431 |
| 11 | 26013 (Driffield Trout Stream @ Driffield) | 1.144 | 11 | 2.700 | 0.281 | **0.282** | 0.196 | **0.195** | 2.597 |
| 12 | 36003 (Box @ Polstead) | 1.180 | 61 | 3.900 | 0.311 | **0.313** | 0.082 | **0.080** | 1.001 |
| 13 | 33032 (Heacham @ Heacham) | 1.181 | 53 | 0.449 | 0.297 | **0.298** | 0.129 | **0.128** | 0.234 |
| 14 | | | | | | | | | |
| 15 | Rejected Stations | | | | | | | | |
| 16 | 26017 (Ings Beck @ South Newbald) | 0.368 | 22 | 0.502 | 0.215 | 0.216 | 0.060 | 0.059 | |
| 17 | | | | | | | | | |
| 18 | | | | | | | | | |

# Appendix E Surface Water Drainage Strategy

BURO HAPPOLD

# Begbroke Innovation District

## Outline Drainage Strategy

## BEG-BUR-XX-XX-RP-XX-00001-Drainage

**0052188**

19 July 2023

Revision P01

| Revision | Description | Issued by | Date | Checked |
|---|---|---|---|---|
| P01 | Draft Issue | TW | 19/07/23 | JW |

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| | |
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| date | **19/07/2023** |
| approved | **John Waiting** |
| signature | |
| date | |

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# Glossary

| Term | Definition |
|---|---|
| BID | Begbroke Innovation District |
| CC | Climate Change |
| EA | Environmental Agency |
| LLFA | Lead Local Flood Authority |
| OCC | Oxfordshire County Council |
| OUD | Oxford University Development |
| SuDS | Sustainable Drainage Systems |
| TW | Thames Water |

# 1 Introduction

## 1.1 Background

This outline drainage strategy has been prepared by Buro Happold on behalf of the Oxford University Developments Ltd. (OUD), in support of an outline planning application for the Begbroke Innovation District (BID).

In preparing the strategy, the existing foul and surface water drainage infrastructure has been assessed regarding the demands of the development proposals. In addition, the impact of the proposed surface water infrastructure on existing water courses has been reviewed in conjunction with a flood risk assessment to ensure no increased flows or flood risk will occur.

The strategy has also drawn on information contained in the following documents

- Masterplan and Area Schedule, (HB, Jan 2023).
- Utilities Asset Report (Groundwise, July 2022).
- Green Infrastructure Parameter Plan (HB, May 2023).
- Flood Risk Assessment (Buro Happold, May 2023).
- Local Standards and Guidance for Surface Water Drainage on Major Development in Oxfordshire (Oxfordshire County Council, December 2021)
- Hydrock Desk Study review and GIR 19114-HYD-XX-XX-RP-GE-1002-S2-P7.

The report sets out the anticipated measures that could be incorporated into the detailed design and later planning stages in order to control both the quantity and quality surface water and quantity of foul water discharged from the Site.

Detailed foul and surface water designs are anticipated to be submitted to the local planning authority prior to the commencement of the relevant part of the Proposed Development, following consultation with relevant stakeholders as necessary. This will ensure that the foul and surface water drainage details are appropriately designed and controlled.

## 1.2 Site Description

The Site is located within the administrative boundary of Oxfordshire County Council (acting as the Lead Local Flood Authority) and within Cherwell District Council (acting as the Local Planning Authority). The Site location is shown in Figure 1-1 and the Site extents shown in Figure 1-2. It is located approximately 5 miles northwest of Oxford, in between the villages of Begbroke, Kidlington and Yarnton. The total Site area is approximately 170ha.

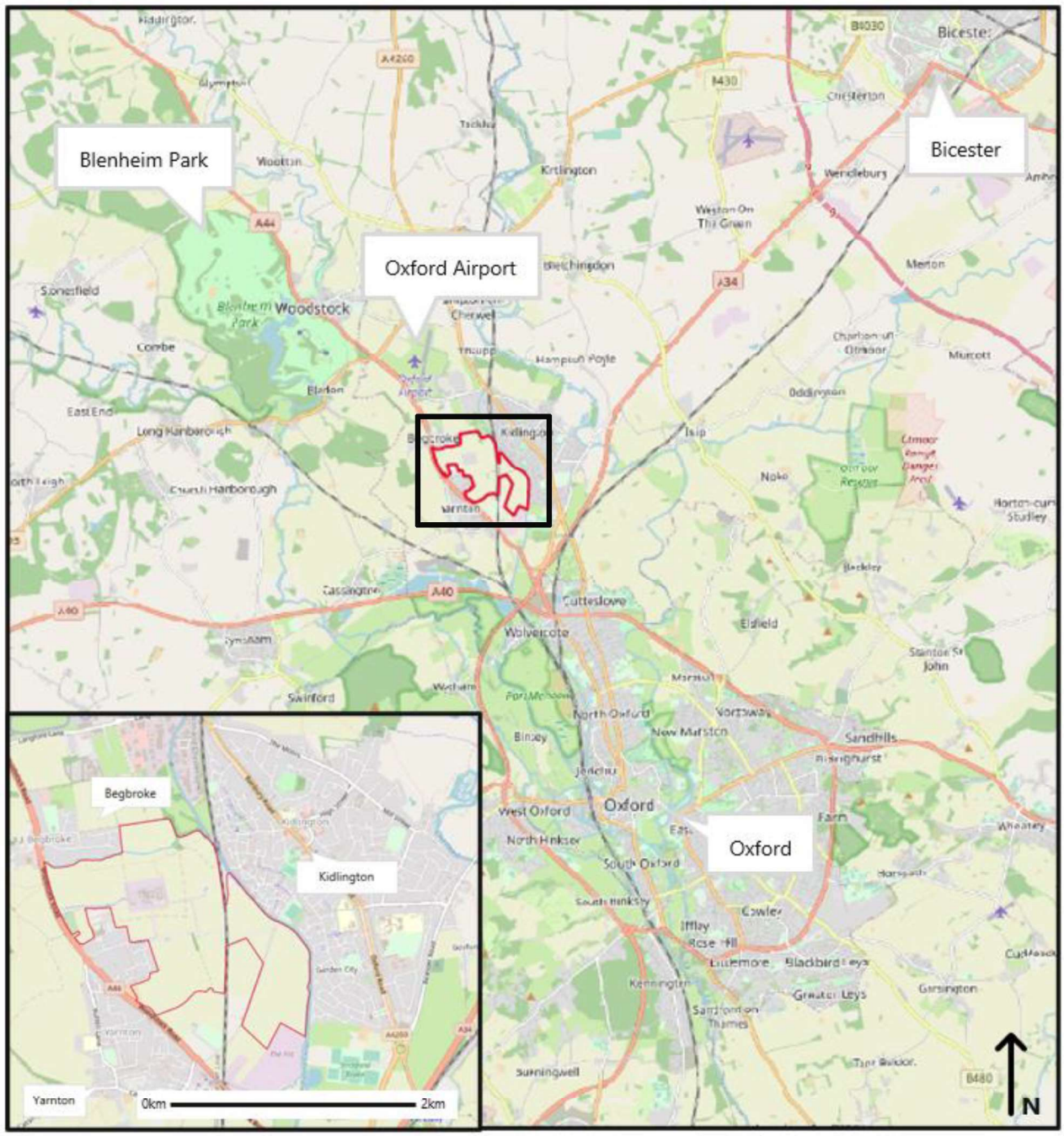


**Figure 1—1 – Site Location and Red Line Boundary**

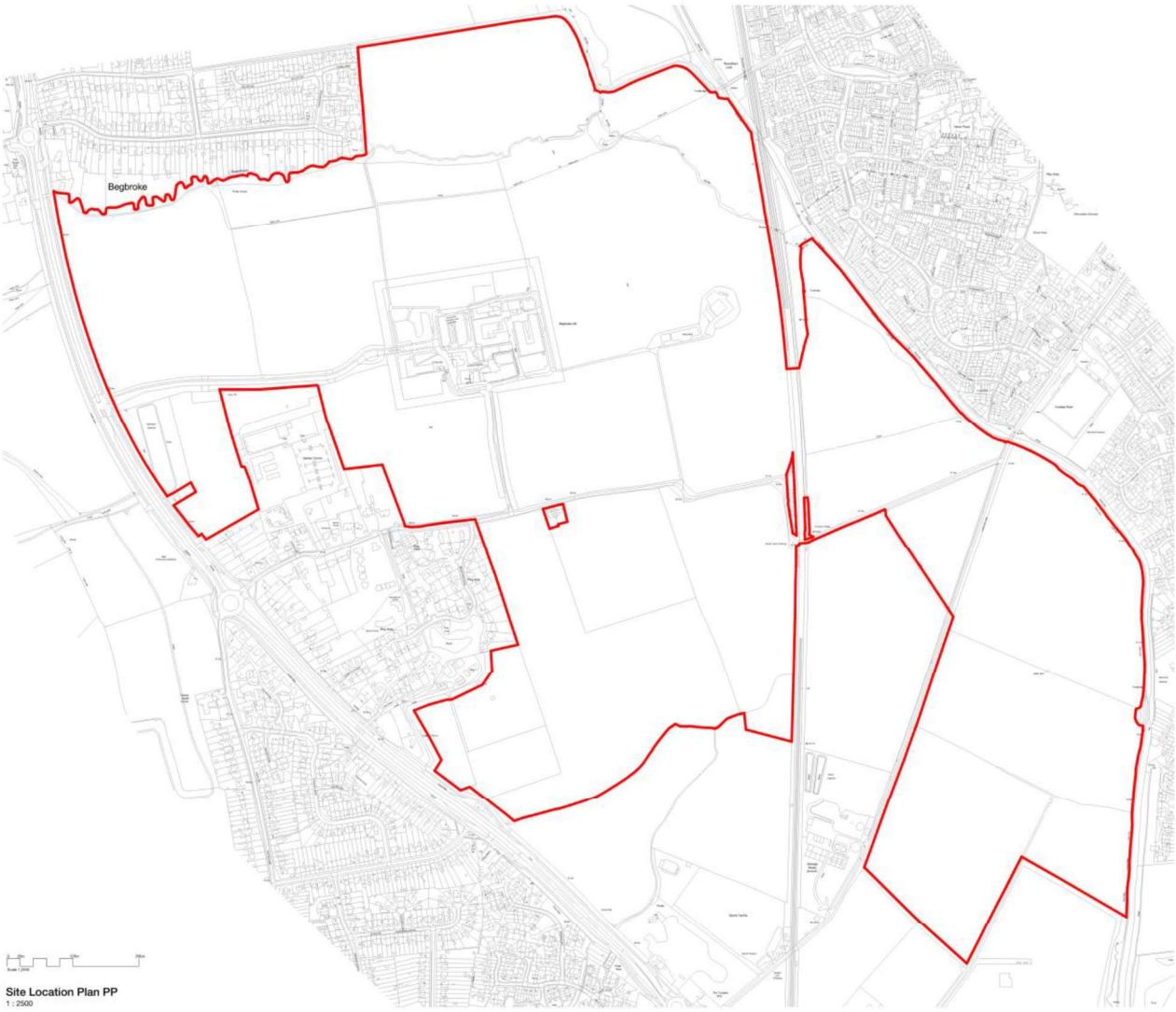


**Figure 1—2 – Site Red Line Boundary (Hawkins Brown, BEG-HBA-SW-00-SK-A-SK80)**

The Site is bound by the A44 Woodstock Road to the west, Rowel Brook to the north and Oxford Canal to the east. The Cherwell Valley railway line intersects the Site from north to south, in the east of the Site. Oxford Airport is located to the north of the Site.

The Site mainly comprises open greenfield land used for arable farming, with Begbroke Science Park (BSP) located at the centre. A number of individual dwellings are situated within the Site boundary, and the Yarnton Home and Garden Centre sits within the west of the Site. Rushy Meadows site of Special Scientific Interest (SSSI) is situated adjacent to the north-eastern boundary of the Site, adjacent to the Oxford Canal.

Access to BSP is provided via Begbroke Hill connecting with the A44 in the west. A number of key roads intersect the Site, providing east/west access, including Begbroke Hill and Sandy Lane. Sandy Lane crosses both the Cherwell Valley railway line (via level crossing) and Oxford Canal (via bridge) on its route towards Yarnton Lane and into Kidlington.

## 1.3 Proposed Development

The Proposed Development is a phased, mixed-use development which would encompass the expansion of the existing Begbroke Science Park, residential and associated amenity, education, and community uses. The Description of Development is as follows:

- Up to 215,000 square metres gross external area of residential floorspace within Use Class C3/C4 and large houses of multiple occupation (Sui Generis);
- Supporting social infrastructure including secondary school/primary school(s) (Use Class F1); health, indoor sport and recreation, emergency, and nursery facilities (Class E(d)-(f))
- Supporting retail, leisure and community uses, including retail (Class E(a)), cafes and restaurants (Class E(b)), commercial and professional services (Class E(c)), local community uses (Class F2), and other local centre uses within a Sui Generis use including public houses, bars and drinking establishments (including with expanded food provision), hot food takeaways, venues for live music performance, theatre, and cinema.
- Up to 155,000 square metres gross external area of flexible employment uses including research and development, office and workspace and associated uses (Use E(g)), industrial (Use Class B2) and storage (Use Class B8) in connection with the expansion of Begbroke Science Park;
- Highway works, including new vehicular, cyclist and pedestrian roads and paths, improvements to the existing Sandy Lane and Begbroke Hill road, a bridge over the Oxford Canal, safeguarded land for a rail halt, and car and cycle parking with associated electric vehicle charging infrastructure;
- Landscape and public realm, including areas for sustainable urban drainage systems, allotments, biodiversity areas, outdoor play and sports facilities (Use Class F2(c));
- Utility, energy, water, and waste water facilities and infrastructure;
- together with enabling and associated works, including temporary meanwhile uses.

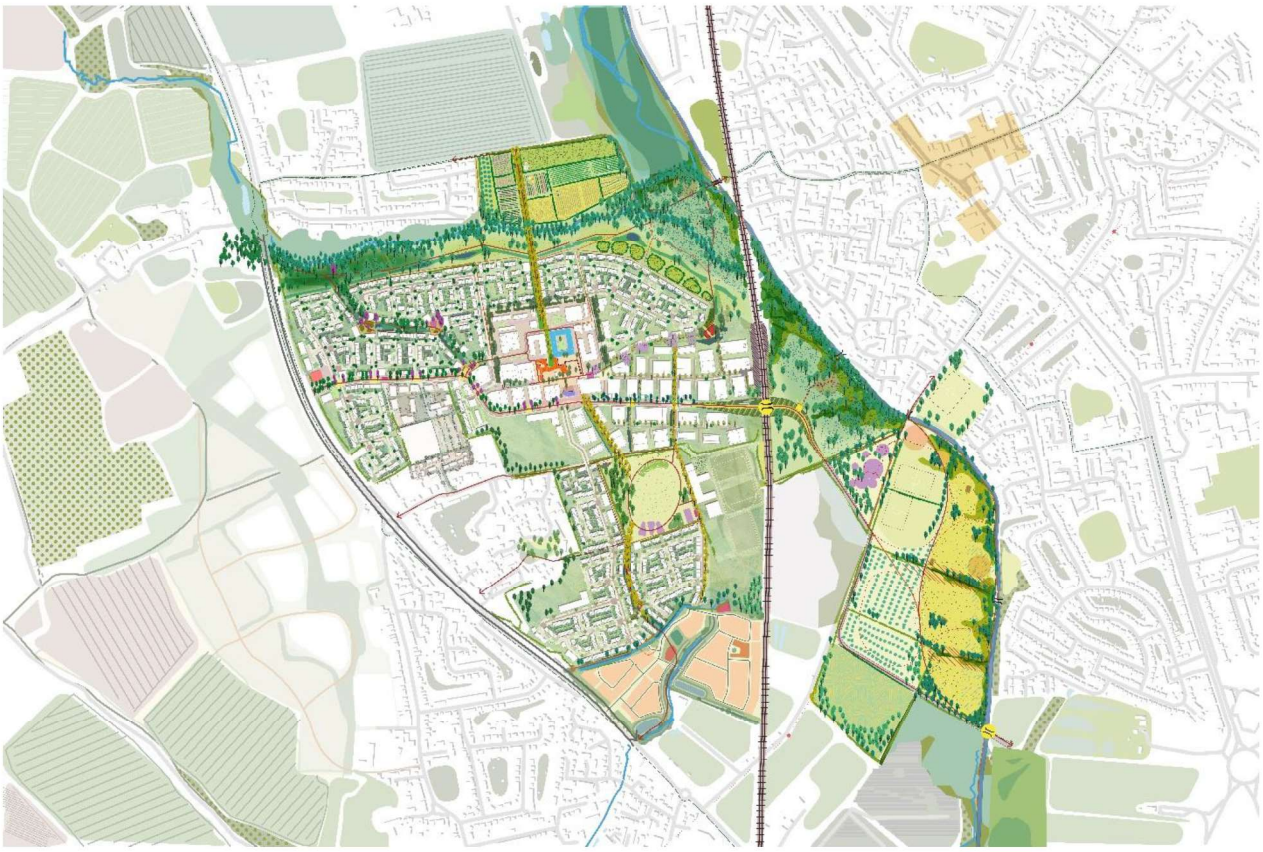

**Figure 1—3 – Illustrative Masterplan Layout**